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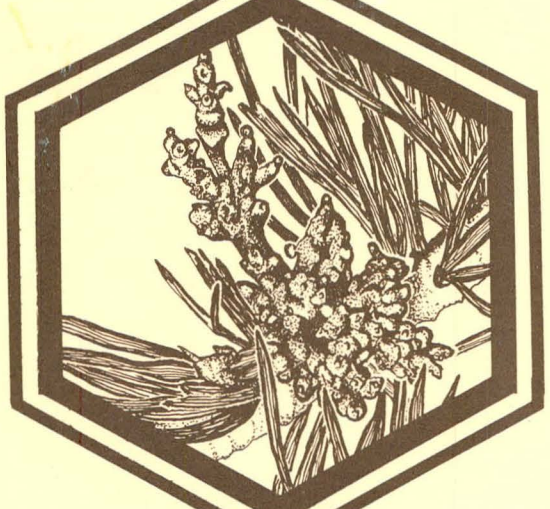

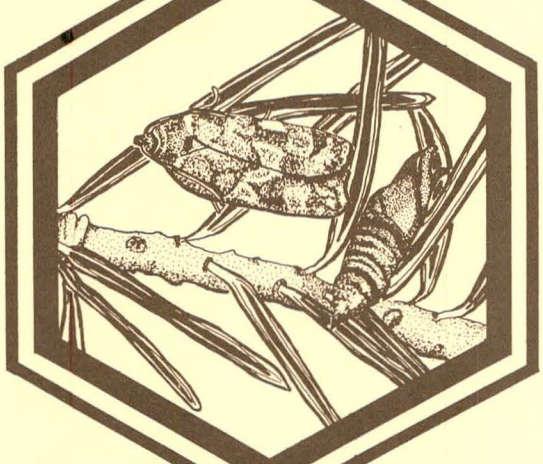

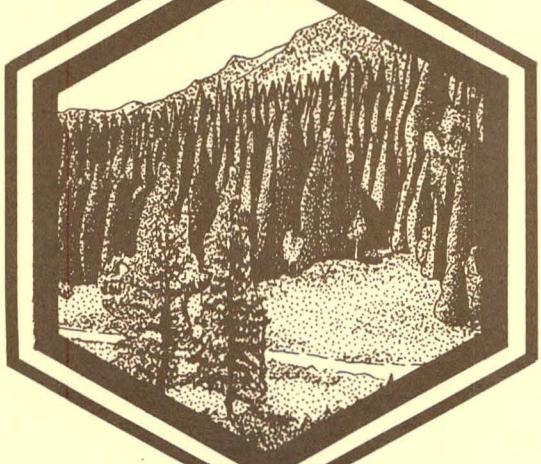

REPORT No. 80-8

SELECTION OF SPRAY OPERATIONS CRITERIA FOR THE WITHLACOOCHEE STATE SEED ORCHARD PROJECT

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June 1980

SELECTION OF SPRAY OPERATIONS CRITERIA FOR THE WITHLACOOCHEE STATE SEED ORCHARD PROJECT[1]

J. E. Rafferty and R. K. Dumbauld[2]

ABSTRACT

The USDA-Forest Service CBG spray dispersion and deposition model is used to determine the optimum swath width, aircraft flight altitude and other spray operations criteria pertinent to the conduct of the Forest Service spray project in the Withlacoochee State Seed Orchard near Brooksville, Florida during February 1980. The model calculations included estimates of the spray deposition patterns at the top of the canopy and at the ground.

INTRODUCTION

The USDA-Forest Service (FS) has found that conventional mist and hydraulic sprayers used to deliver pesticides to the cones, conelets and foliage of southern pines do not provide adequate coverage in the upper half of the crown where most of the seed cones are produced. For this reason, the Forest Insect and Disease Management office at Asheville, North Carolina (SA-FIDM) proposed to study the feasibility of using aerial application techniques for the control of cone losses due to coneworm infestation. In the winter of 1979, SA-FIDM Asheville and Methods Application Group, Davis, California (SA-FIDM/MAG) planned a pilot project to evaluate aerial application technology for southern seed forests to be conducted in the Withlacoochee State Seed Orchard near Brooksville, Florida. As part of the planning for the project, the Cramer/Barry/Grim (CBG) aerial spray dispersion and deposition model (Dumbauld, Rafferty and Bjorklund, 1977) was used to determine the optimum swath width, aircraft flight altitude and other spray parameters pertinent to the conduct of the pilot project. In the model calculations, deposition patterns were estimated at the canopy top and at the ground. The spray parameters which, when used in the model, produced the most uniform deposition patterns were selected as the best estimates of the parameter values to be used in the pilot project.

The following principal variables were considered in the model calculations:

-Two aircraft types - fixed wing and rotary wing.

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1 Prepared for USDA-Forest Service, Forest Insect and Disease Management, Methods Application Group, Davis, CA, under Contract 53-01S8-9-6260; John W. Barry, USDA-Forest Service, Project Officer.

2 H. E. Cramer Co., Inc., P. O. Box 8049, Salt Lake City, UT 84108.

-Two flight levels - 20 and 5 feet above the canopy.

-Two swath widths - 30 and 60 feet.

-Two meteorological regimes - early and late morning.

This report describes the aircraft characteristics, orchard characteristics and the meteorological regimes considered in the calculations and presents the spray operations criteria selected for the pilot project.

AIRCRAFT AND ORCHARD CHARACTERISTICS AND METEOROLOGICAL REGIMES

Aircraft Characteristics

Because the actual aircraft types to be used during the spray project had not been determined when the study began, the Pawnee Brave fixed-wing aircraft and the Bell G-3 helicopter were selected as typical of the small aircraft used in orchard spray operations. SA-FIDM/MAG provided the drop-size distributions for water-base insecticides sprayed from these aircraft which had been determined from previous spray trials employing the aircraft. The drop-size distributions and the gravitational settling velocities of the mean drop in each size category are shown in Table 1 for the Pawnee Brave and in Table 2 for the Bell G-3. The gravitational settling velocities were calculated using a technique suggested by McDonald (1960).

The trees in the Withlacoochee orchard are planted in rows with a separation of 30 feet (9.14 meters). For this reason and because the rows would likely be used by the aircraft pilot to maintain the proper orientation of the flight path, we selected swath widths of 30 and 60 feet (9.14 and 18.29 meters) for use in the model calculations. An application rate of 5 gallons per acre suggested by SA-FIDM/MAG is equivalent to a model source strength of 42.77 grams per meter for the 30-foot (9.14-meter) swaths and 85.54 grams per meter for 60-foot (18.29 meter) swaths.

In previous model calculations (Dumbauld, Rafferty and Bjorklund, 1977), the spray cloud for each swath was assumed to sink with the aircraft wake vortex to a height of one-half the aircraft wing span (b/2) above the canopy top. This height was used as the effective source height in the model calculations and the vertical distance from the aircraft flight altitude to b/2 was used to specify the vertical and alongwind source dimensions. For the orchard spray project, the specific aircraft flight altitudes above the canopy top were 5 feet (1.52 meters) and 20 feet (6.10 meters). The values of b/2 are 18.4 feet (5.87 meters) for the Pawnee and 18.6 feet (5.64 meters) for the Bell G-3. The specified flight altitudes are too close to the top of the canopy to allow us to use the above rationale involving the vortex sink rate to determine the effective source heights and source dimensions. Alternatively, we arbitrarily assigned the following values to the source dimensions σ_0 and the effective source heights of H':

Table 1. Drop-size distribution and settling velocities for the Pawnee Brave fixed-wing aircraft.

Drop-Size Category	Mean Drop Diameter (μm)	Mass Fraction	Settling Velocity ($m\ sec^{-1}$)
1	45.2	.001	.0891
2	74.0	.009	.203
3	106	.02	.341
4	133	.03	.479
5	159	.04	.632
6	197	.10	.793
7	241	.10	.996
8	283	.10	1.22
9	353	.20	1.54
10	424	.10	1.83
11	490	.10	2.09
12	607	.10	2.66
13	745	.04	3.26
14	897	.03	3.83
15	1067	.02	4.42
16	1184	.01	4.78

Table 2. Drop-size distribution and settling velocities for the Bell G-3 helicopter.

Drop-Size Category	Mean Drop Diameter (μm)	Mass Fraction	Settling Velocity ($m\ sec^{-1}$)
1	50.7	.001	.110
2	84.2	.009	.234
3	119	.02	.404
4	146	.03	.548
5	169	.04	.675
6	198	.10	.796
7	232	.10	.944
8	260	.10	1.09
9	304	.20	1.34
10	351	.10	1.54
11	389	.10	1.69
12	440	.10	1.89
13	496	.04	2.12
14	552	.03	2.38
15	631	.02	2.77
16	887	.01	3.80

$$\sigma_o = \begin{cases} 1.5\ b/4.3 & ;\ H=6.10m \\ b/4.3 & ;\ H=1.52m \end{cases} \quad (1)$$

$$H' = \begin{cases} b/2 & ;\ H=6.10m \\ 1.52m & ;\ H=1.52m \end{cases} \quad (2)$$

In the above expressions, b is the wing span for the Pawnee Brave aircraft and the rotor diameter for the G-3 helicopter; H is the flight altitude.

Orchard Characteristics

Two coincident stands in the Withlacoochee orchard were to be used in evaluating pine orchard spray operations, one stand planted with slash pine and the other planted with Ocala sand pine. After visual inspection of the trees in the orchard, a Foliage Type III was assigned to the slash pine and Foliage Type IV[3] was assigned to the Ocala sand pine as required by the canopy penetration model. The probability of penetration PRPEN was set equal to 0.38 for Foliage Type III and to 0.13 for Foliage Type IV. The spacing of the trees along the rows in the Withlacoochee orchard is 15 feet (4.57 meters) and, as noted above, there is 30 feet (9.14 meters) between rows. Thus, the tree density D_t for both foliage types is 96.8 stems per acre. The widths of typical trees in the two stands as a function of tree height, which were estimated from photographs made during a visit to the orchard, are shown in Table 3. The average height of the slash pines was estimated to be 12 meters and the average height of the Ocala pines was estimated to be 11 meters. Table 4 presents impaction efficiencies for the drop-size distributions for the Pawnee aircraft shown in Table 1 and Table 5 presents similar data for the Bell G-3 drop-size distribution shown in Table 2. The impaction efficiencies were calculated using Sell's law (see Dumbauld, Rafferty and Bjorklund, 1977). Impaction efficiencies are shown for both the early and late morning meteorological regimes because the wind speeds in the canopy are different for the two regimes. A tree element diameter of 13 centimeters was used in all the calculations.

Meteorological Regimes

The two meteorological regimes considered in the calculations, early and late morning, were chosen as representative times of day when the spray trials would be conducted. The vertical profiles of wind speed above and below the forest canopy were developed by matching a power-law wind profile for flat, open areas with profiles for above-canopy winds suggested by Oliver (1971) and a below-canopy profile suggested by Fritschen, et al. (1970) for isolated conifer stands with no understory.

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[3] Grim and Barry (1975) developed the foliage typing system.

Table 3. Tree envelope widths in meters versus height.

Height (m)	Tree Type	
	Slash Pine	Ocala Sand Pine
.5	0.21	0.26
1.5	0.19	0.26
2.5	0.19	7.2
3.5	3.8	7.1
4.5	6.6	7.9
5.5	6.2	6.6
6.5	5.8	6.2
7.5	5.4	5.9
8.5	5.0	5.2
9.5	4.0	3.7
10.5	3.3	1.6
11.5	1.6	0

Table 4. Impaction efficiencies for the Pawnee aircraft and the drop-size distribution in Table 1.

Drop-Size Category	Slash Pine		Ocala Sand Pine	
	Early Morning	Late Morning	Early Morning	Late Morning
1	.0058	.101	.0527	.0946
2	.150	.270	.141	.254
3	.307	.555	.290	.520
4	.483	.873	.456	.819
5	.690	1	.652	1
6	1	1	1	1
7	1	1	1	1
8	1	1	1	1
9	1	1	1	1
10	1	1	1	1
11	1	1	1	1
12	1	1	1	1
13	1	1	1	1
14	1	1	1	1
15	1	1	1	1
16	1	1	1	1

Table 5. Impaction efficiencies for the Bell G-3 Aircraft and the drop-size distribution in Table 2.

Drop-Size Category	Slash Pine	
	Early Morning	Late Morning
1	.0702	.127
2	.194	.350
3	.387	.699
4	.582	1
5	.780	1
6	1	1
7	1	1
8	1	1
9	1	1
10	1	1
11	1	1
12	1	1
13	1	1
14	1	1
15	1	1
16	1	1

The power-law expression for the vertical profile of wind speed over flat, open areas is given by

$$\bar{u}\{z\} = \bar{u}_R \left(\frac{z}{z_R}\right)^p \qquad (3)$$

where

$\bar{u}\{z\}$ = mean wind speed at height z
$\bar{u}_R$ = mean wind speed at the reference height z_R
p = power-law coefficient

The zero-plane displacement profile for above the canopy suggested by Oliver (1971) is

$$\bar{u}\{z\} = \frac{u^*}{k} \ln\left(\frac{z-D}{z_o}\right) \qquad (4)$$

where

u^* = friction velocity
k = von Karman constant (0.4)
D = zero-plane displacement
= 0.75 H_c
H_c = canopy height
z_o = roughness length

In the wind profile calculations, z_o was set equal to 1.1 for early morning and to 0.96 for late morning.

We assumed that the vertical wind profile in open areas was given by Equation (3) using the mean wind speeds at a reference height of 2 meters and the power-law coefficients shown in Table 6. Values of the standard deviations of the wind azimuth angle σ_A and wind elevation angle σ_E, as well as values of the depth of the surface mixing layer H_m, used in the model calculations are also listed in Table 6.

To obtain the above-canopy wind profile, Equation (4) was set equal to Equation (3) at a height of 3 H_c (see Smith, et al., 1972) above the canopy and values of u^* were calculated for the early and late morning meteorological regimes. The wind profile from the top of the canopy to a height 3 H_c was then calculated from Equation (4). Finally, the normalized profile for winds below an isolated conifer stand with no understory given by Fritschen, et al (1970), with the wind speed at the top of the canopy set equal to the value given by Equation (4), was used to obtain the below-canopy wind profile presented in Table 7. The mean cloud transport speeds $\bar{u}_T$ in Table 7 were calculated following the procedure outlined by Dumbauld, Bowman and Rafferty (1980, Appendix A).

Table 6. Meteorological parameters for early and late morning for the Withlacoochee spray project.

Meteorological Parameter	Early Morning	Late Morning
$\bar{u}_R\{z_R=2m\}$ (m sec^{-1})	2	5
p	.3	.15
$\sigma_A\{\tau=10$ min$\}$ (deg)	5	8
σ_E (deg)	1.67	2.67
H_m (m)	100	200

Table 7. Mean wind speeds within the canopy and mean cloud transport speeds.

a. Mean canopy wind speeds (m s^{-1}).

Canopy Level	Slash Pine			Ocala Sand Pine		
	Height (m)	Early Morning	Late Morning	Height (m)	Early Morning	Late Morning
Base (1)	1.5	1.39	2.46	1.38	1.27	2.30
(2)	4.5	1.22	2.16	4.13	1.12	2.03
(3)	7.5	1.19	2.10	6.89	1.10	1.98
Top (4)	10.5	1.31	2.31	6.93	1.21	2.17

b. Mean cloud transport speeds (m s^{-1}).

Aircraft Type	Flight Altitude (m)	Slash Pine		Ocala Sand Pine	
		Early Morning	Late Morning	Early Morning	Late Morning
Pawnee Brave	1.52	1.82	3.15	-	-
	6.10	2.44	4.11	2.38	4.06
Bell G-3	1.52	1.82	3.15	-	-
	6.10	2.41	4.07	-	-

RESULTS OF THE MODEL CALCULATIONS

Optimum Swath Width and Flight Altitude

Model calculations of deposition at the canopy top and at the ground were made for the 16 combinations of the 4 principal variables cited in the Introduction and, in selected cases, for the two types of trees. The results of a significant portion of the calculations are plotted in Figures 1 through 12. All the calculations shown in the figures were made for 10 swaths perpendicular to the wind. In the figures, the positive downwind distance scale begins at the last downwind swath.

Figure 1 shows deposition in mass units for the Pawnee aircraft flying at 20 feet (6.1 meters) above a slash pine canopy. The swath width is 30 feet (9.1m) and the time of day is early morning. For comparison purposes, Figure 2 shows deposition under identical conditions except the swath width is 60 feet (18.3m). Note that in Figure 1 the ratio of mass deposited in the peaks and troughs of the deposition distribution at the canopy top is about a factor of 1.25, while in Figure 2 the ratio is closer to 2.5. Thus, while the average deposition over the canopy and at the base of the canopy is nearly identical, the use of a 60-foot swath greatly increases the variability of the deposition at the top of the canopy. The variability is reduced in both cases at the base of the canopy, but is smaller when a 30-foot swath spacing is maintained. Figures 3 and 4 are similar to Figures 1 and 2, except the deposition is expressed in drop units. Figures 3 and 4 also indicate that an increase in swath width increases the variability in the drop deposition pattern, but the increase in variability is smaller than that shown by the mass deposition pattern. Figures 5 and 6 respectively show deposition by mass and by drops during the late morning hours for the Pawnee aircraft flying 30-foot swath widths at a height of 20 feet above the canopy. A comparison of Figures 1 and 2 for the early morning hours with Figures 5 and 6 shows that the increased wind speeds above and below the canopy top and the increased turbulence levels present in the late morning hours reduce the range of the deposition levels between the peaks and troughs of the deposition patterns.

The variability between the peaks and troughs in the deposition pattern is also increased as the flight altitude is reduced to 5 feet (1.52m) above the canopy. Figure 7 shows the calculated mass deposition patterns at the top of the canopy and at the ground for a Pawnee flying 30-foot swath widths at a height of 5 feet above the canopy during the early morning hours. Comparison of Figure 7 with Figure 1, which refers to a flight altitude of 20 feet above the canopy under the same meteorological conditions and a 30-foot swath width, illustrates the increased variability in the peaks and troughs of the deposition patterns at the lower flight altitude. Figure 8 shows drop deposition patterns at the canopy top and at the ground for the Pawnee flying 30-foot swaths at 5 feet above the ground during the early morning hours. The greatest variability in deposition levels occurs, as shown in Figures 9 and 10, when the Pawnee flies 60-foot swaths at a flight altitude of 5 feet above the

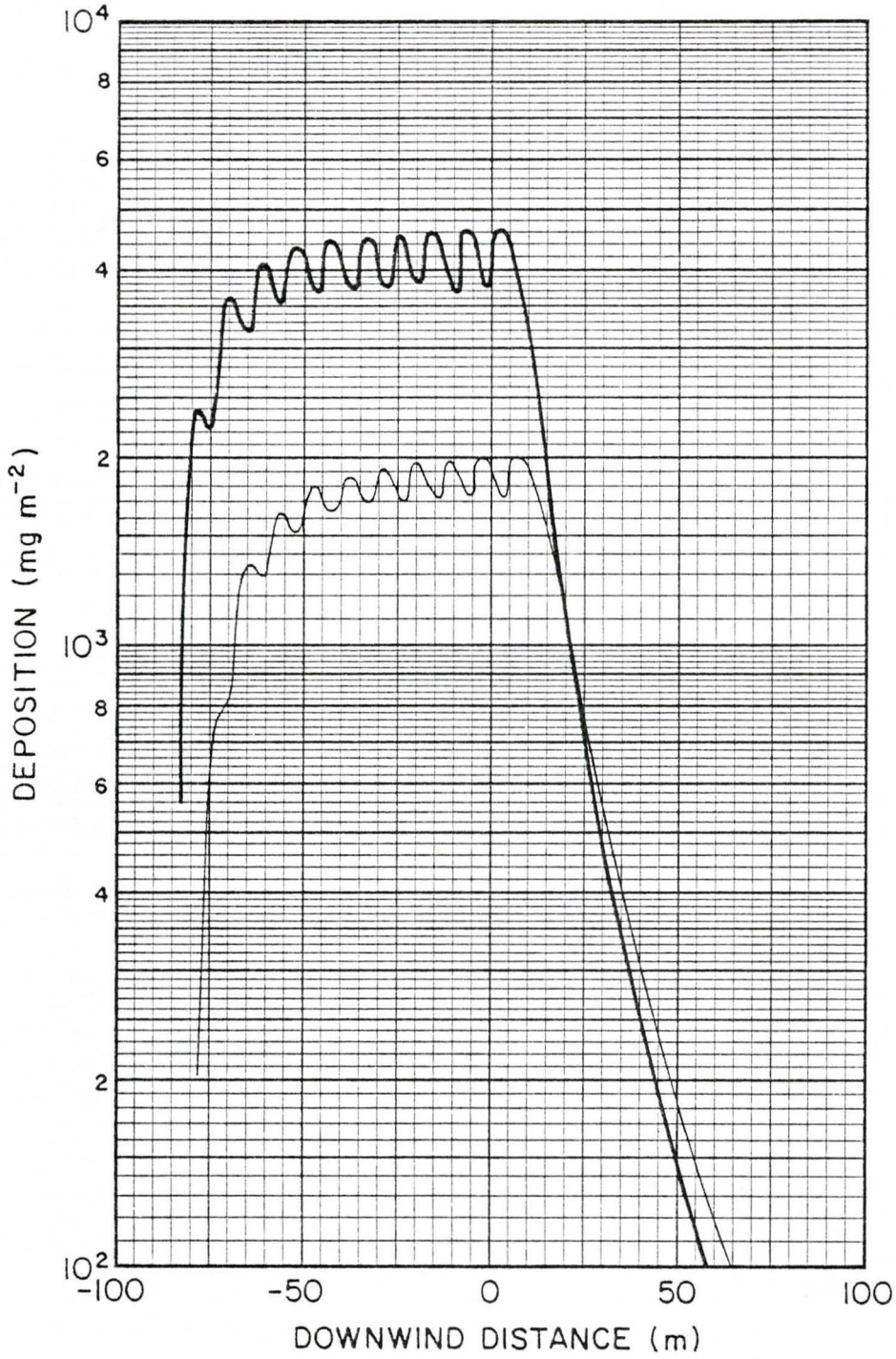

Figure 1. Mass deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Pawnee aircraft flying 30-foot swaths at a flight altitude of 20 feet above a slash pine canopy.

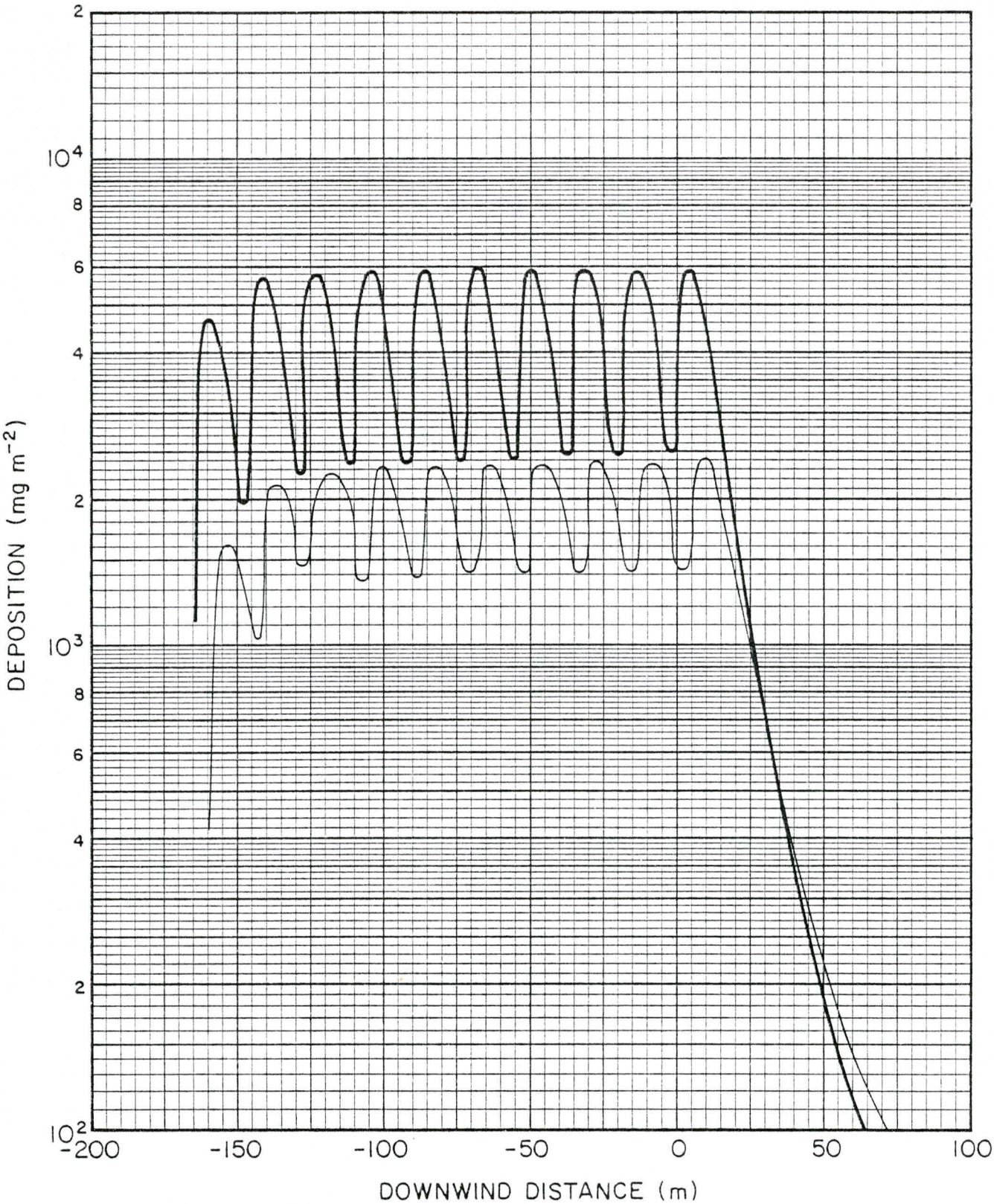

Figure 2. Mass deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Pawnee aircraft flying 60-foot swaths at a flight altitude of 20 feet above a slash pine canopy.

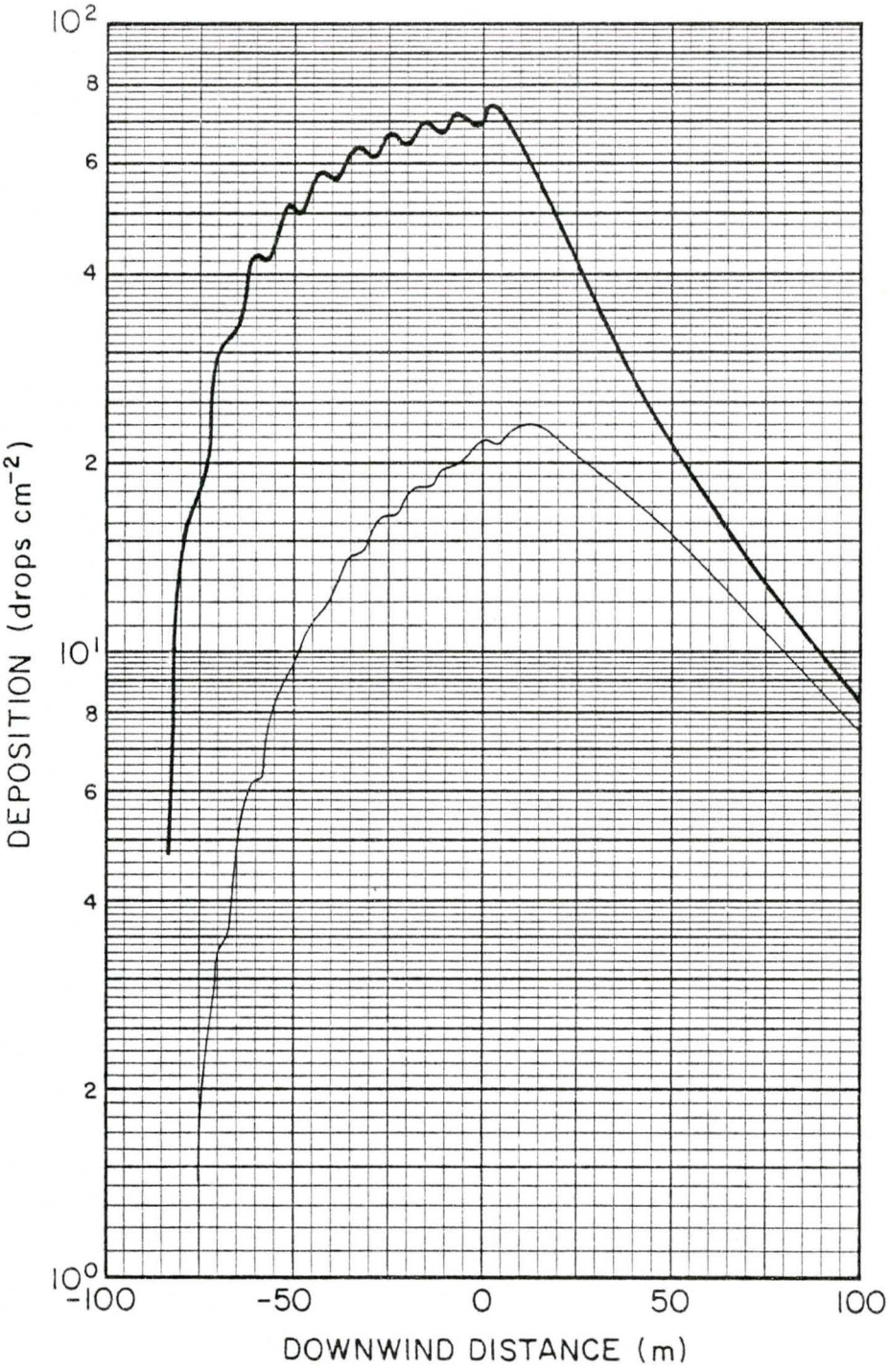

Figure 3. Drop deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Pawnee aircraft flying 30-foot swaths at a flight altitude of 20 feet above a slash pine canopy.

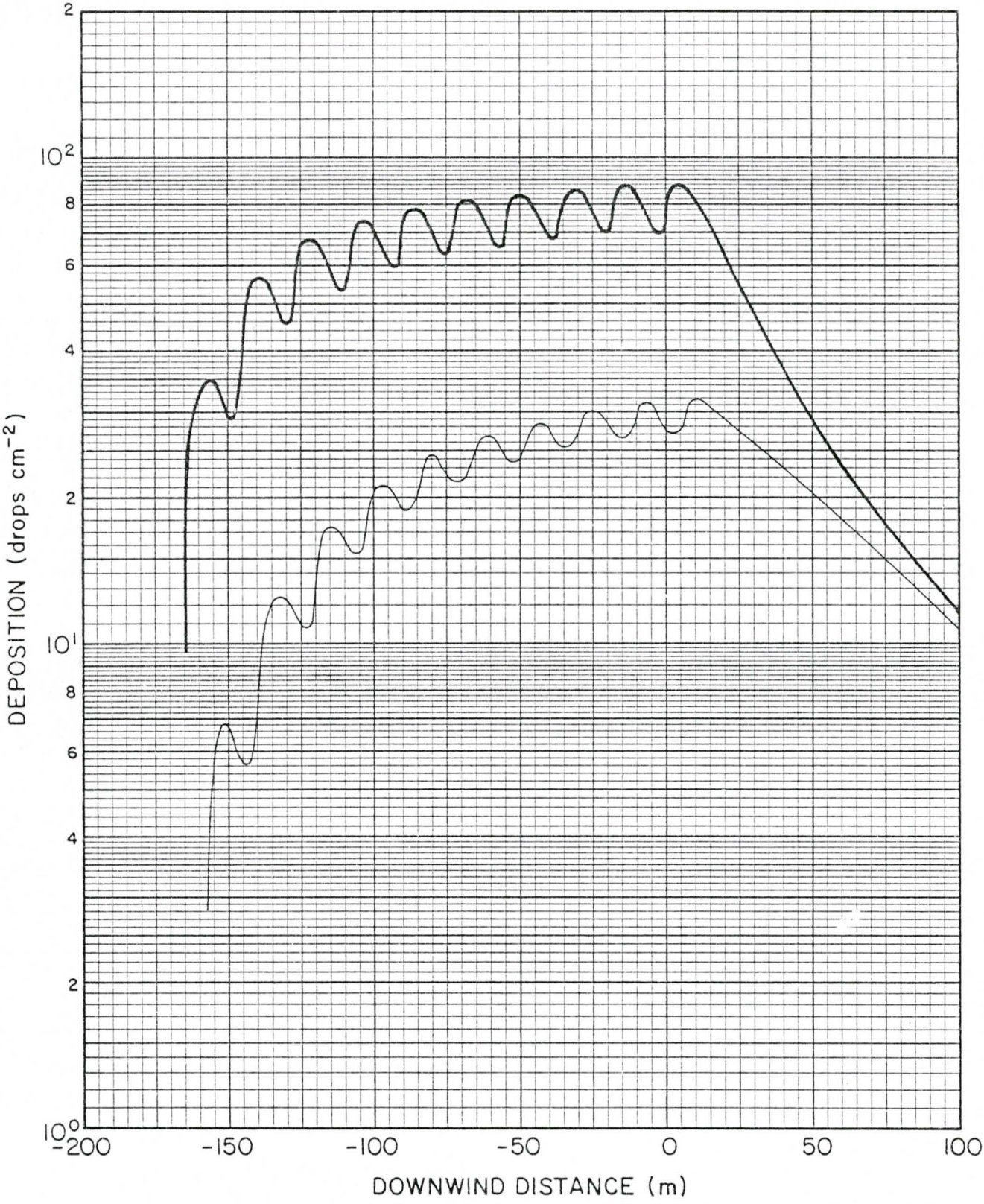

Figure 4. Drop deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Pawnee aircraft flying 60-foot swaths at a flight altitude of 20 feet above a slash pine canopy.

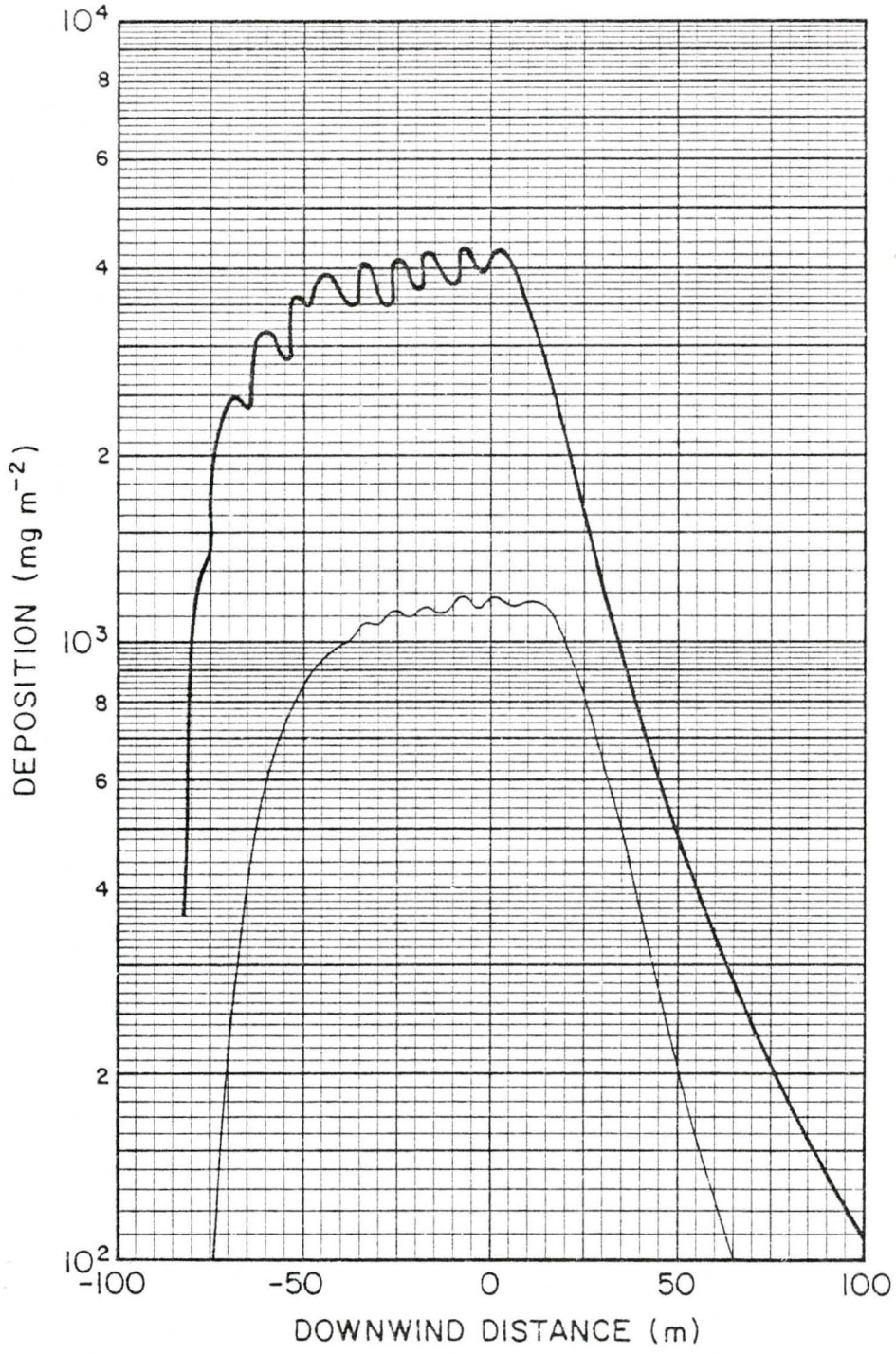

Figure 5. Mass deposition at the canopy top (dark line) and at the ground (light line) during the late morning hours for a Pawnee aircraft flying 30-foot swaths at a flight altitude of 20 feet above a slash pine canopy.

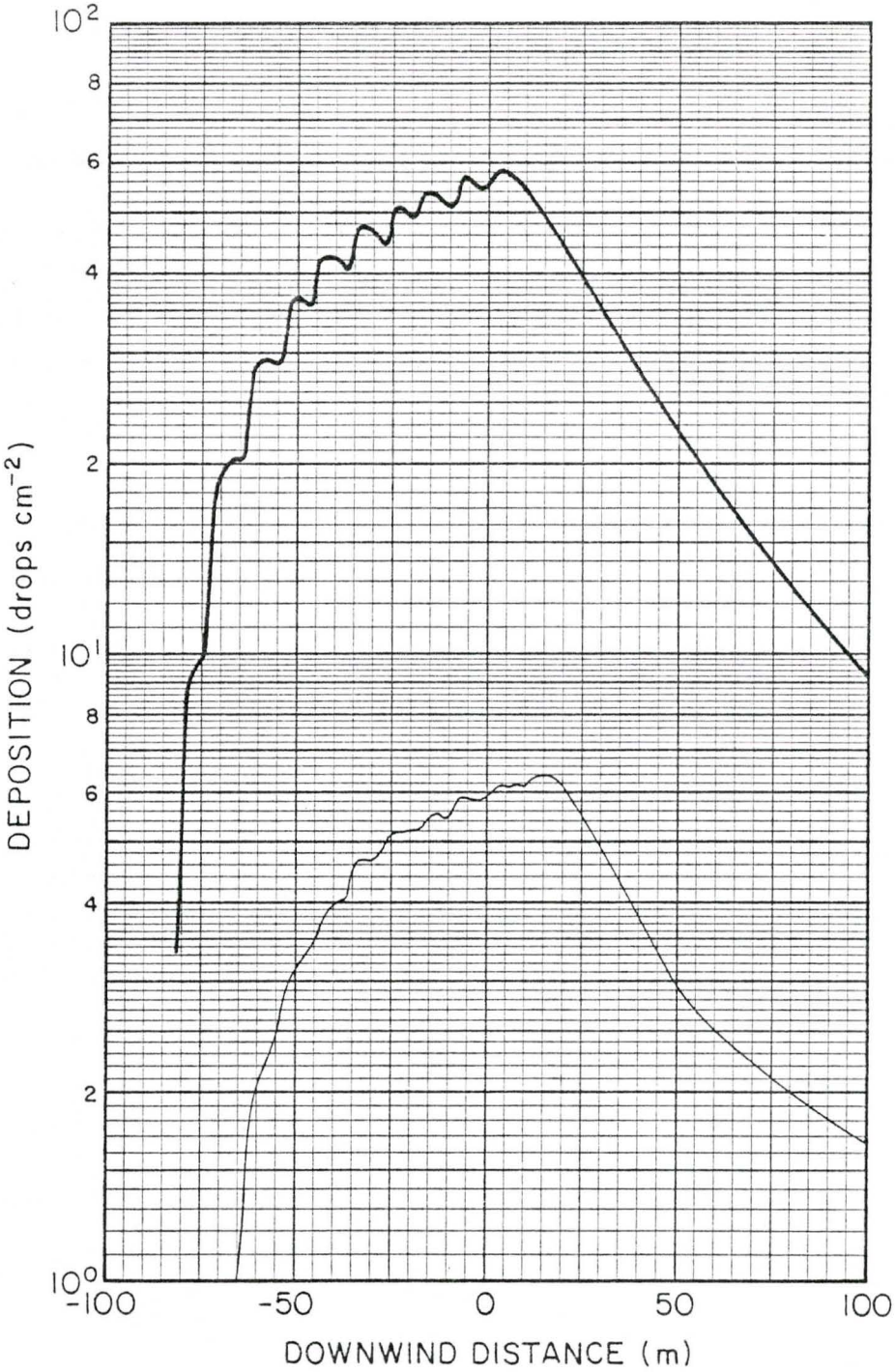

Figure 6. Drop deposition at the canopy top (dark line) and at the ground (light line) during the late morning hours for a Pawnee aircraft flying 30-foot swaths at a flight altitutde of 20 feet above a slash pine canopy.

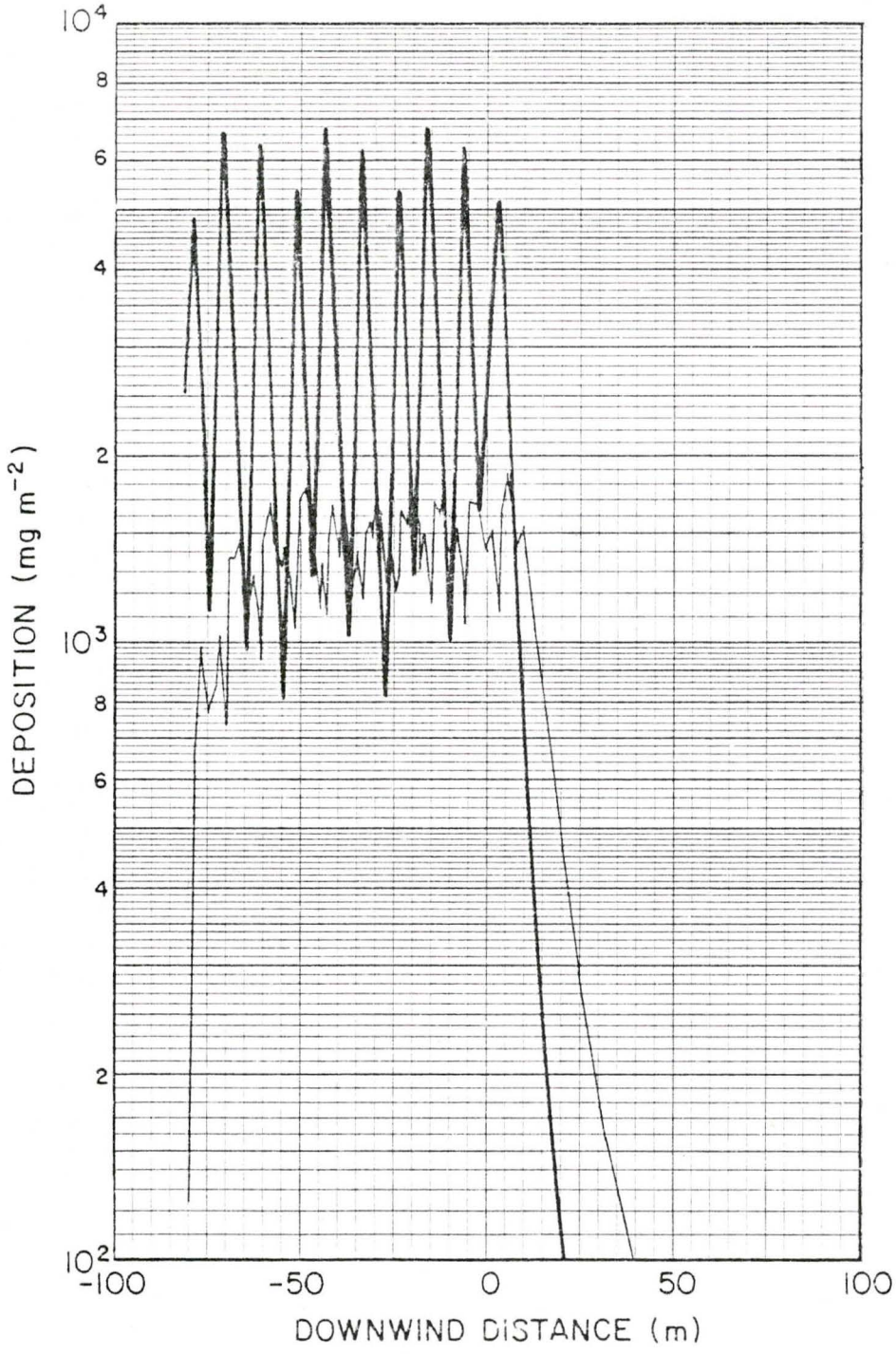

Figure 7. Mass deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Pawnee aircraft flying 30-foot swaths at a flight altitude of 5 feet above a slash pine canopy.

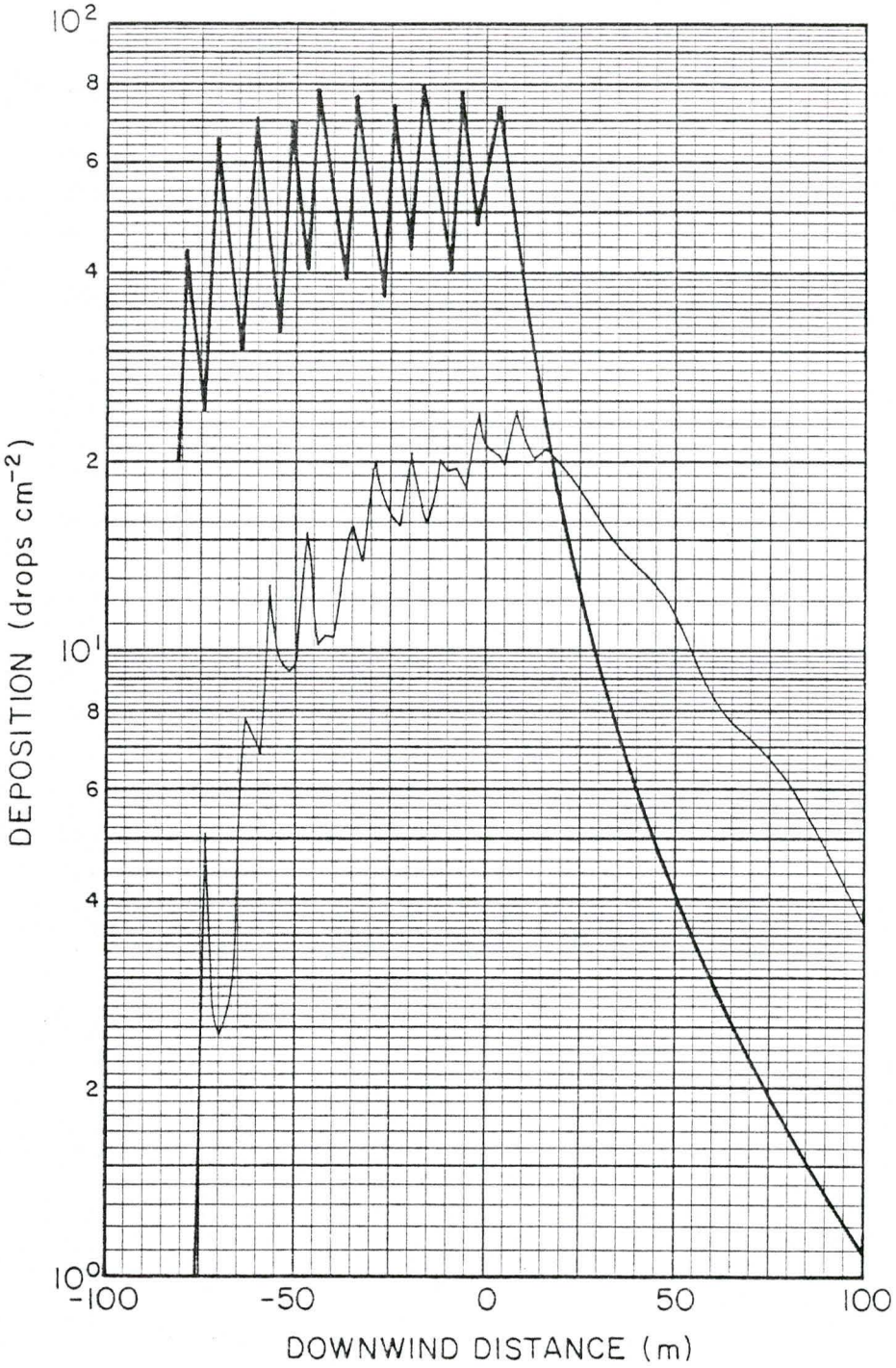

Figure 8. Drop deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Pawnee aircraft flying 30-foot swaths at a flight altitude of 5 feet above a slash pine canopy.

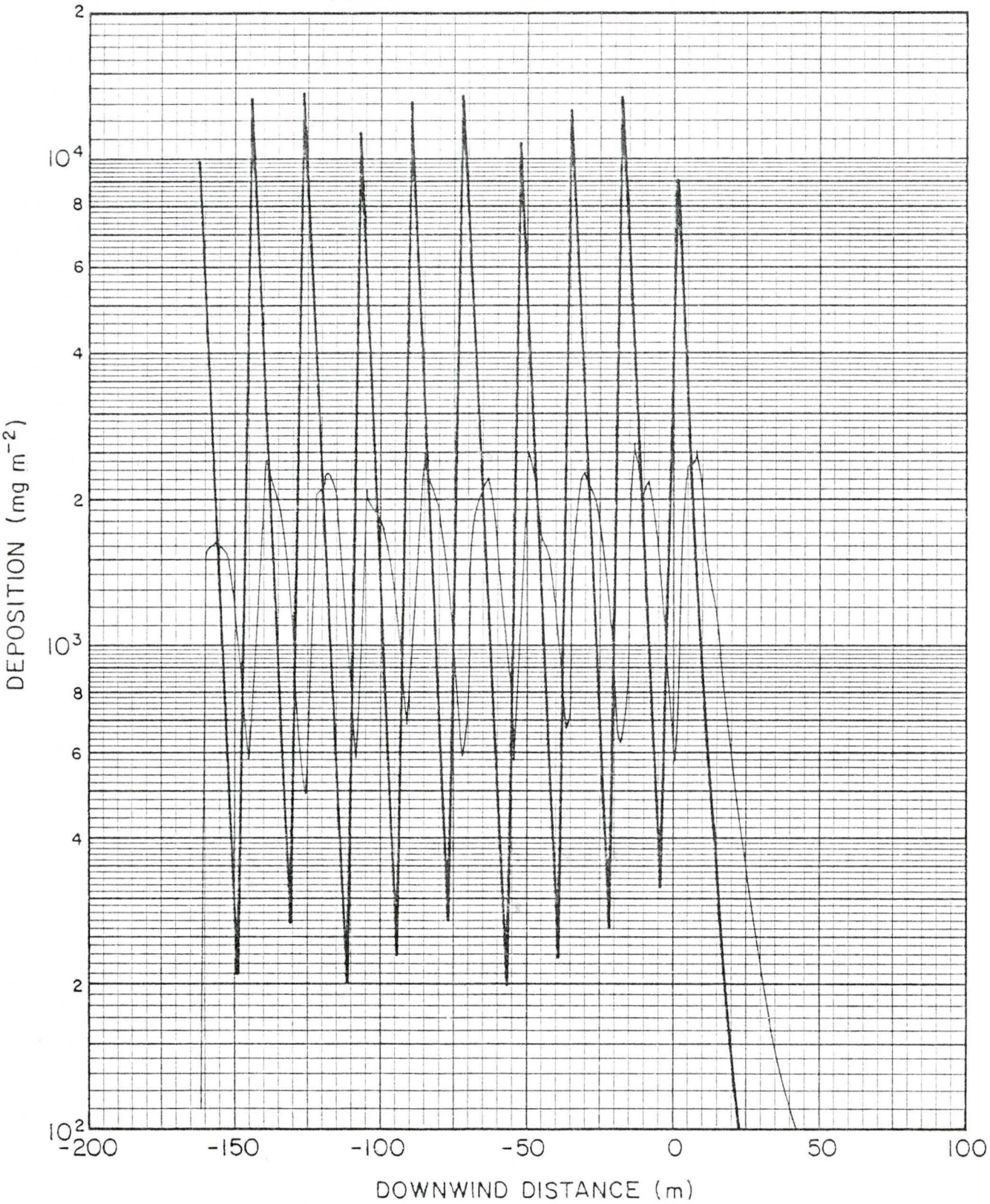

Figure 9. Mass deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Pawnee aircraft flying 60-foot swaths at a flight altitude of 5 feet above a slash pine canopy.

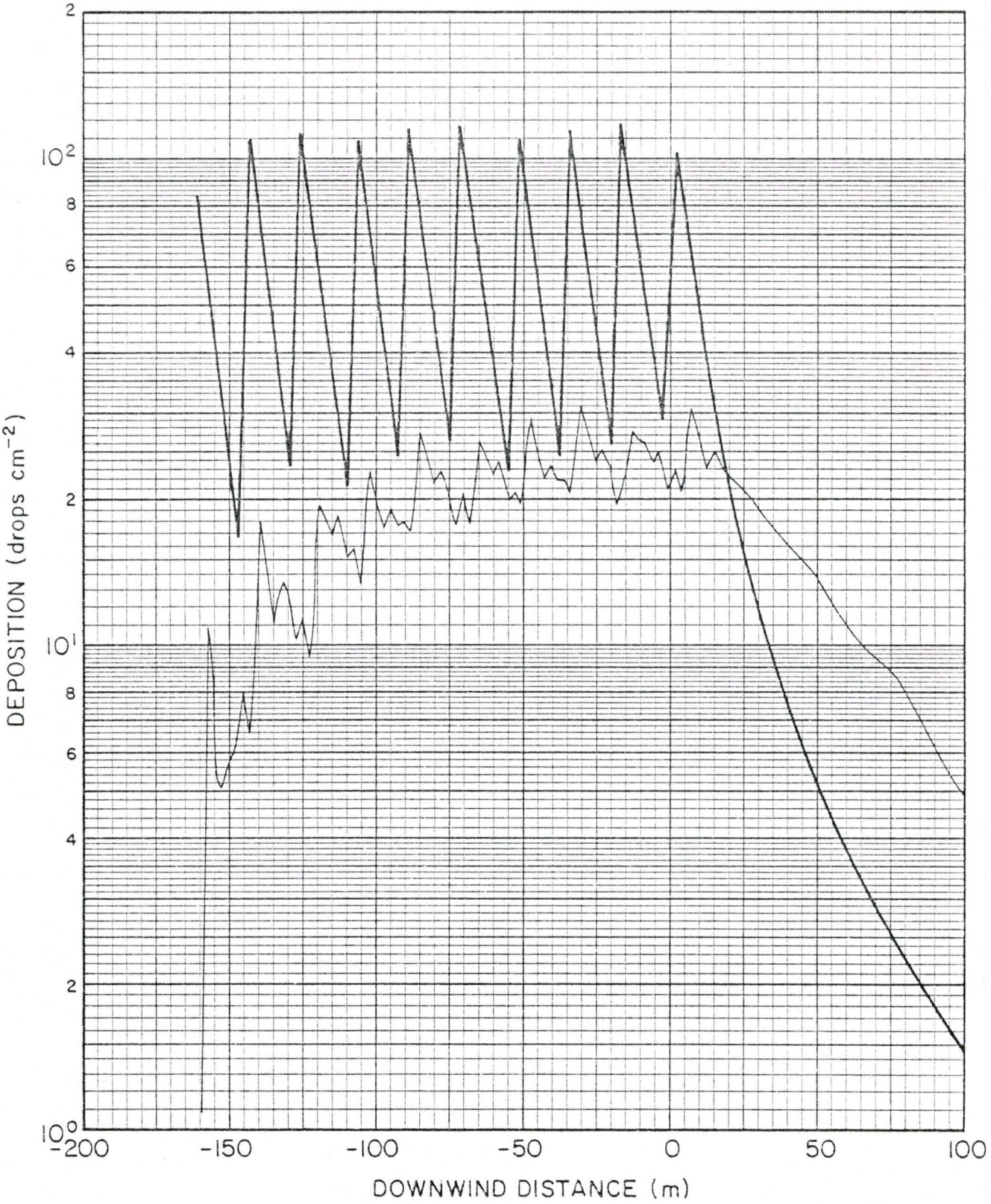

Figure 10. Drop deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Pawnee aircraft flying 60-foot swaths at a flight altitude of 5 feet above a slash pine canopy.

canopy during the early morning hours. The results of the calculations thus indicate that the preferred swath width is 30 feet and the preferred flight altitude is 20 feet for the Pawnee aircraft.

Figure 11 shows the results of calculations for the mass deposition from a Bell G-3 helicopter flying 30-foot swath widths at a 20-foot flight altitude above the slash pine canopy during the early morning hours. Comparison with Figure 1 for the Pawnee aircraft for the same conditions (except for the slightly different drop-size distribution) shows an almost identical pattern at the top of the canopy and only slightly reduced deposition levels at ground-level beneath the canopy. This result might be expected because the assumed wake efects from both the helicopter and the Pawnee are very similar. We therefore conclude that a swath width of 30 feet and flight altitude of 20 feet is also preferred for the helicopter trials.

Figure 12 shows mass deposition at the canopy top and at ground level for the Ocala sand-pine orchard when sprayed by the Pawnee aircraft under the same conditions shown in Figure 1 for the slash pine orchard. Note that the major difference shown in the two figures is that the denser foliage of the Ocala sand pine removes more drops in the canopy and thus the deposition at ground level beneath the canopy is reduced.

To achieve mass deposition levels within the spray area similar to those which would be achieved in a larger spray operation for full-size orchards, Figure 1 shows that a minimum of about six swaths must be flown. Even with this number of swaths, drop deposition levels (see Figure 3) will likely be less than those observed in a full-scale operation.

Effects of Variations In Drop-Size Distributions

Drop-size distributions with volume median diameters of 300 and 400 micrometers with slopes identical to the distribution given in Table 1 were used to investigate the effects of differences in drop-size distribution on the deposition patterns for the Pawnee aircraft spraying the slash pine orchard. Figure 13 shows the mass deposition pattern for a volume median diameter (VMD) of 400 micrometers for a flight altitude and for meteorological conditions identical to those in Figure 1, where the VMD is 350 micrometers. Comparison of Figures 1 and 13 shows that the deposition pattern at the top of the canopy is more variable for the larger drop-size distribution and that slightly more mass penetrates to the ground below the canopy. The drop deposition pattern shown in Figure 14 for a VMD of 400 micrometers should be compared with the drop deposition pattern in Figure 3 for a VMD of 350 micrometers. Because there are fewer drops in the larger drop-size distribution, Figure 14 shows smaller numbers of drops deposited at the canopy top and at the ground. Similar results were obtained using a drop-size distribution with a VMD of 300 micrometers in deposition calculations for the slash pine orchard. In this case, the calculated mass deposition at the top of the canopy and at the ground was similar to the deposition for a VMD of 350 micrometers. However, because the total number

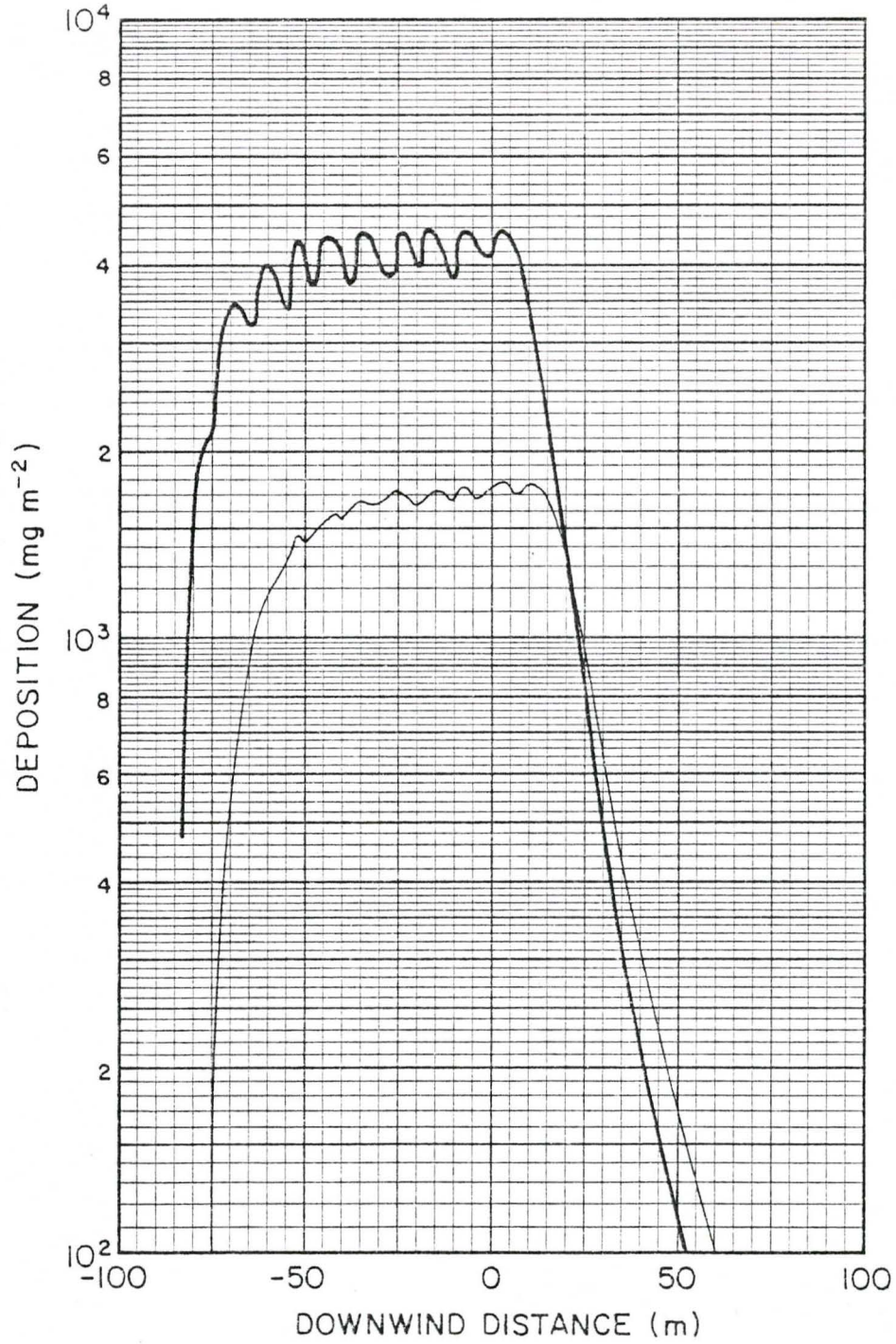

Figure 11. Mass deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Bell G-3 helicopter flying 30-foot swaths at a flight altitude of 20 feet above a slash pine canopy.

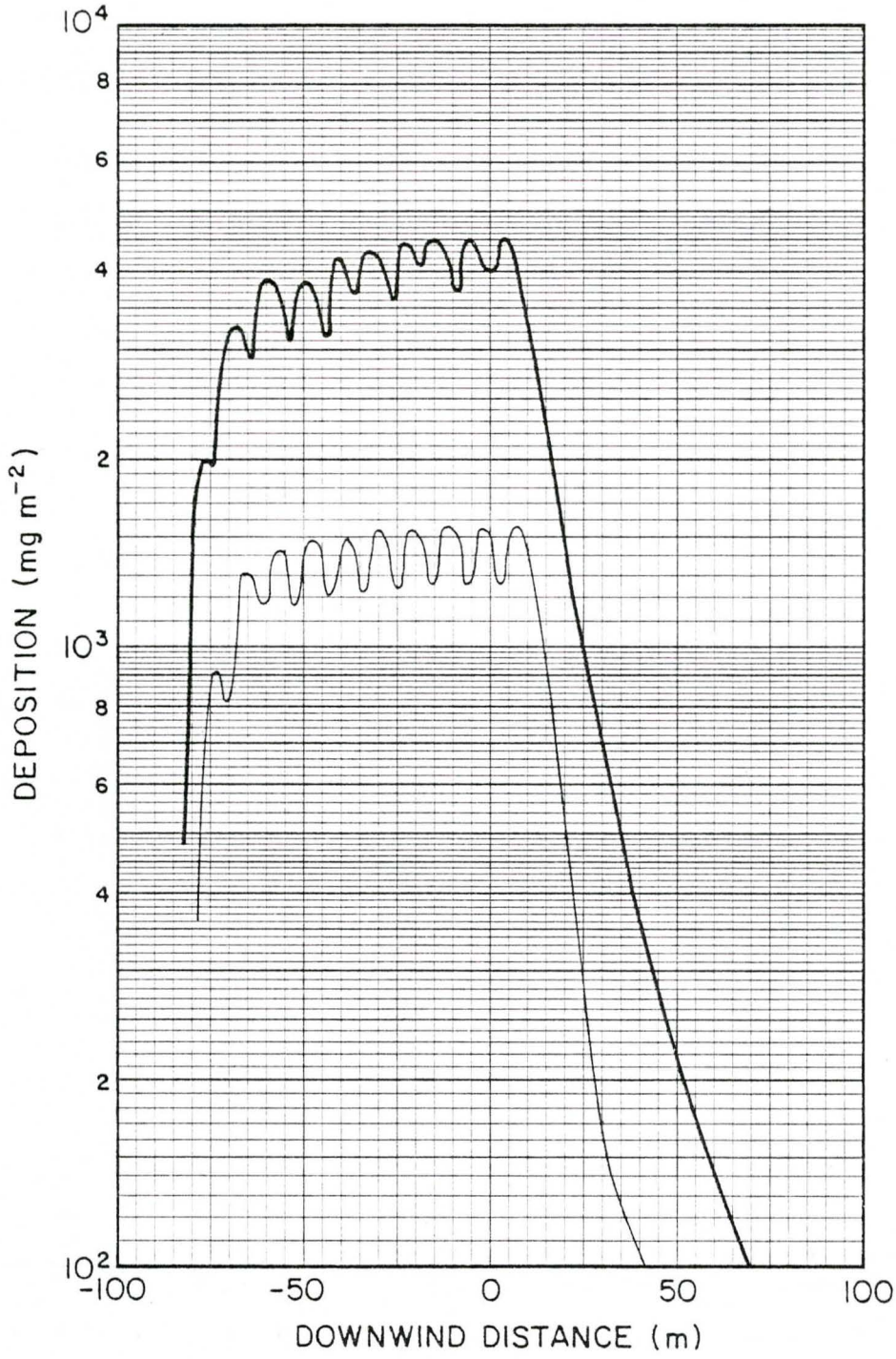

Figure 12. Mass deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Pawnee aircraft flying 30-foot swaths at a flight altitude of 20 feet above an Ocala sand-pine canopy.

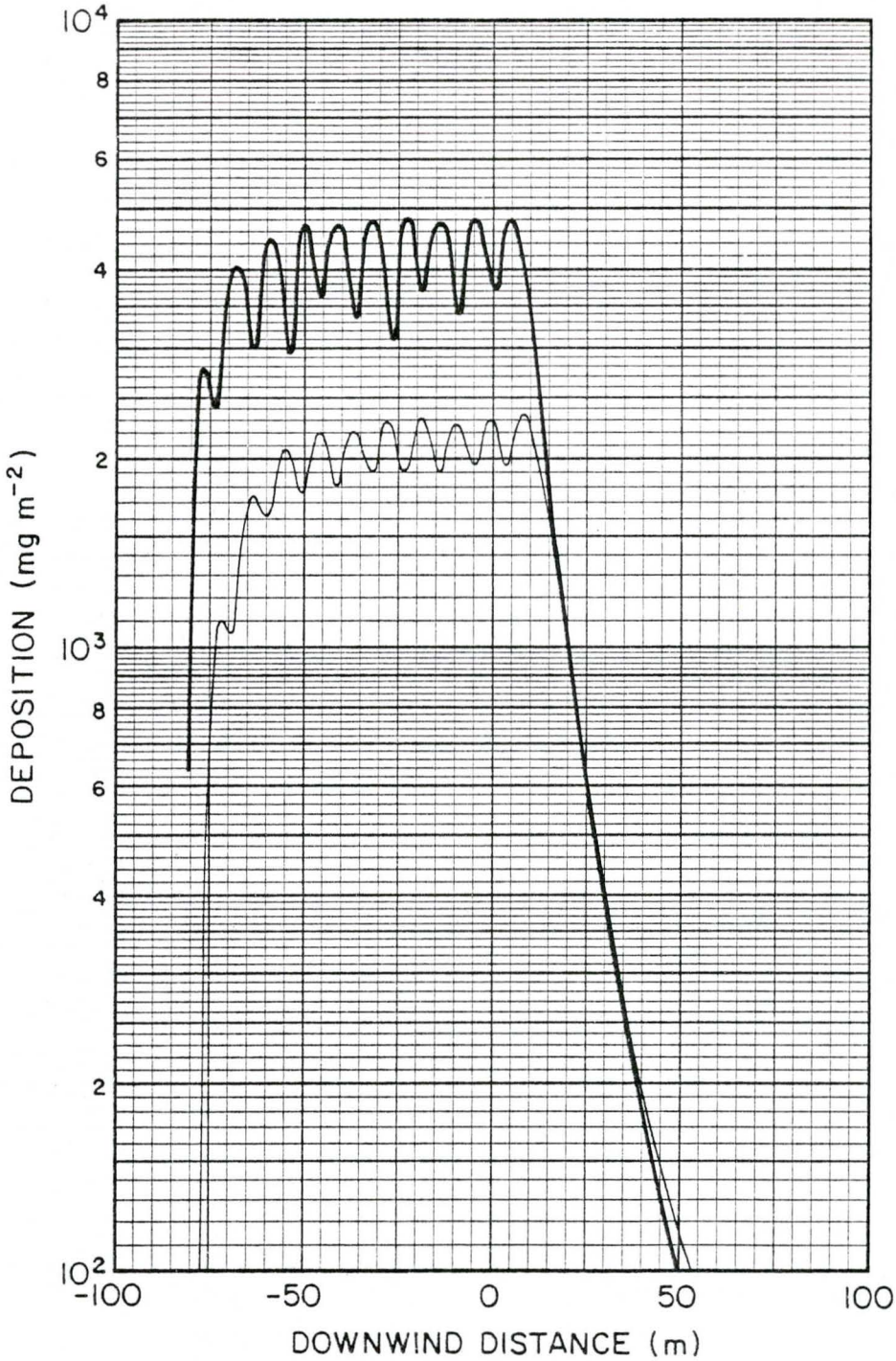

Figure 13. Mass deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Pawnee aircraft flying 30-foot swaths at a flight altitude of 20 feet above a slash pine canopy. Drop-size distribution has a VMD equal to 400 micrometers.

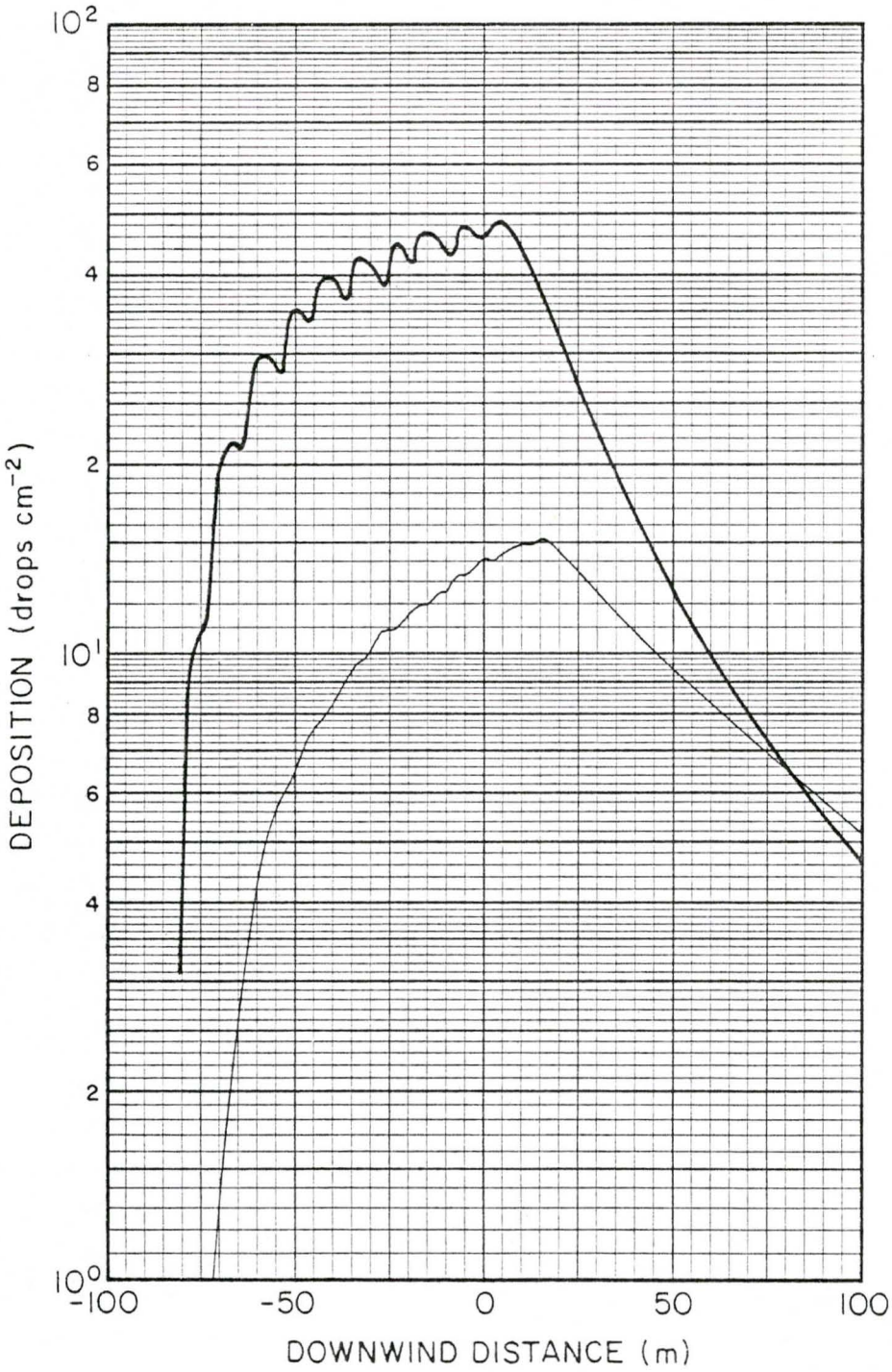

Figure 14. Drop deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Pawnee aircraft flying 30-foot swaths at a flight altitude of 20 feet above a slash pine canopy. Drop-size distribution has a VMD equal to 400 micrometers.

of drops increases as the VMD becomes smaller, the calculated drop deposition is larger for a VMD of 300 micrometers.

Effects of Variations In Wind Direction

Deposition calculations were also made for a mean wind direction above the canopy that was along the flight path (along the tree rows). Figure 15 shows the mass deposition along the middle of the swath downwind from the upwind edge of the spray lines at the top of the canopy and at the ground for a Pawnee aircraft flying 30-foot swaths at 20 feet above the canopy during the early morning hours. As indicated in Figure 15, the mass deposition does not reach a uniform level until about 60 to 100 meters downwind from the upwind edge of the spray pattern. Figure 16 shows the drop deposition pattern for the same conditions, and indicates that drop deposition at the canopy top and at the ground is still increasing at a distance of 300 meters from the upwind edge of the spray pattern. For this reason, the ground sampling lines and tree sampling positions should not be located closer than about 100 meters to the ends of the tree rows at the northern and southern borders of the orchard.

Conclusions and Recommendations

Based on our analysis of the results of spray deposition calculations made using the CBG spray dispersion and deposition model, we recommend the following criteria be used in conducting the spray trials at the Withlacoochee State Seed Orchard:

1. The optimum swath width is 30 feet (9.14m)

2. The optimum flight altitude is 20 feet (6.1m) above the canopy

3. A minimum of 6 swaths should be flown to ensure that the deposition levels within the spray area are similar to those associated with a full-scale operation

4. The spray sampling lines and sampling trees should be located a minimum of 100 meters from the northern and southern boundaries of the orchard

The above criteria apply to the Pawnee Brave and Bell G-3 aircraft.

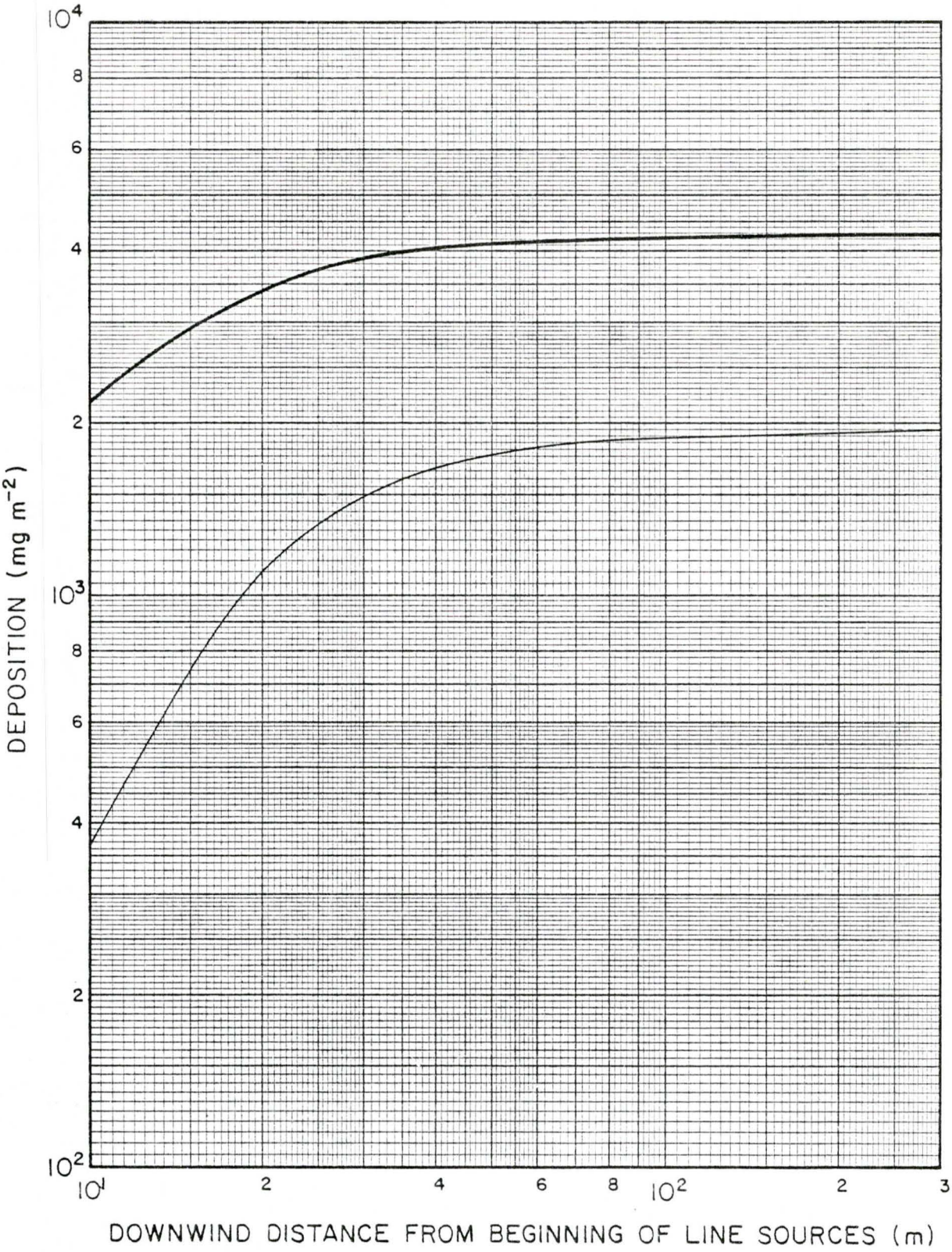

Figure 15. Mass deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Pawnee aircraft flying 30-foot swaths at a flight altitude of 20 feet above a slash pine canopy. Wind direction is along the tree rows.

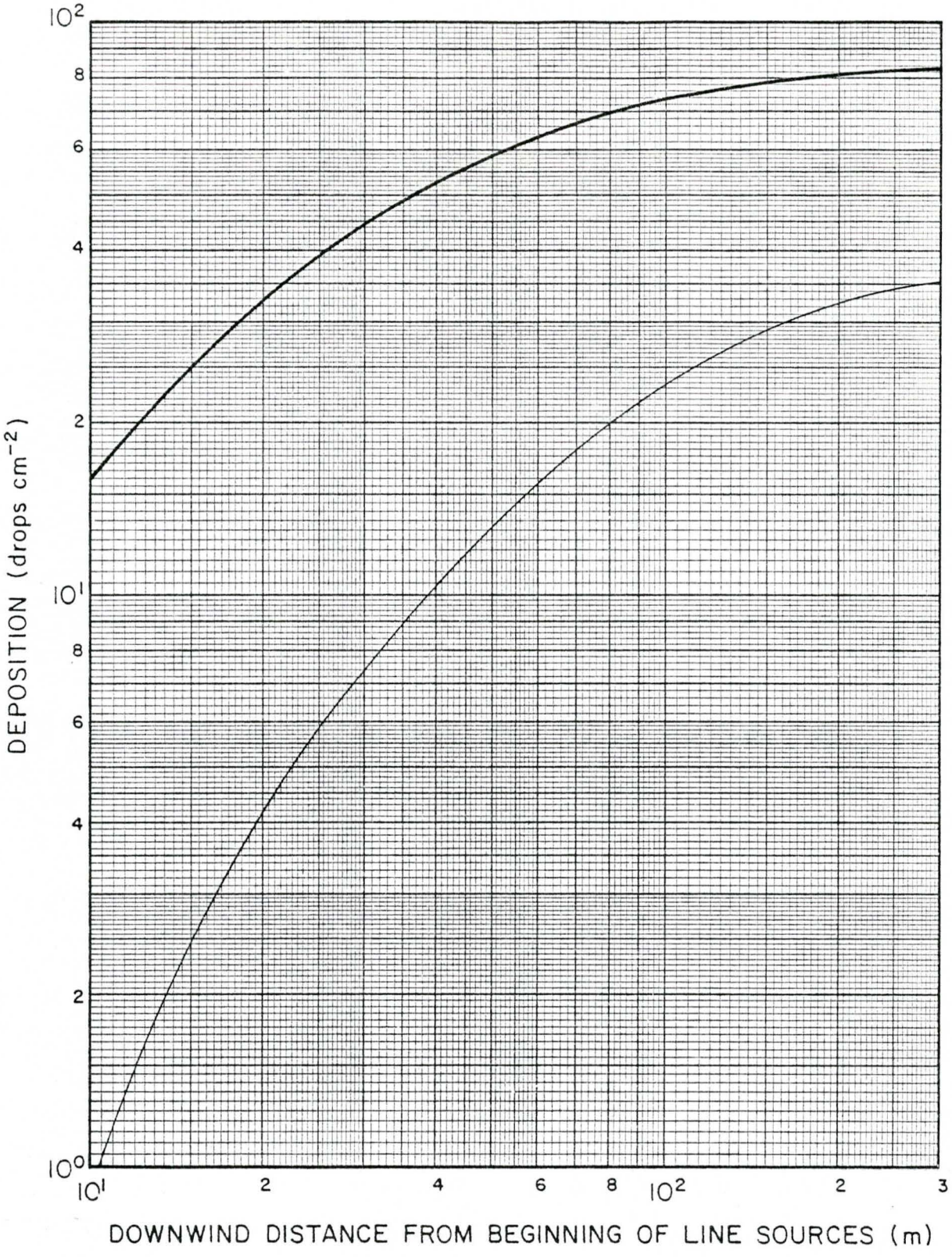

Figure 16. Drop deposition at the canopy top (dark line) and at the ground (light line) during the early morning hours for a Pawnee aircraft flying 30-foot swaths at a flight altitude of 20 feet above a slash pine canopy. Wind direction is along the tree rows.

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